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SEISMIC RESPONSE OF UNSYMMETRIC BUILDING WITH OPTIMALLY PLACED FRICTION DAMPERS

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ABSTRACT

Conventional methods of seismic rehabilitation with concrete shear walls or steel bracing are not considered suitable for some buildings as upgrades with these methods would have required expensive and time consuming foundation work. Supplemental damping in conjunction with appropriate stiffness offers an innovative and attractive solution for the seismic rehabilitation of such structures. This paper deals with the use of friction damper as a passive dissipative device in order to seismic retrofit of existing structures and discusses the optimal placement criteria. To fulfill this objective, six storey and ten storey L-shaped buildings have been modeled with five different damper location formats in SAP2000 subjected to El Centro and Utterkashi earthquake records. Non-Linear Modal Time History Method has been used for the analysis and base shear, joint displacement, member forces and hysteresis energy has been compared to find out most optimal damper location format.

Key words: friction damper, non-linear modal time history analysis, optimization, slip load

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1. INTRODUCTION

Severe ground shaking induces lateral inertial forces on buildings, causing them to sway back and forth with amplitude proportional to the energy fed in. If a major portion of this energy can be consumed during building motion, the seismic response can be considerably improved. The manner in which this energy is consumed in the structure determines the level of damage.

The use of bracing systems equipped with dissipative devices is relatively new technique for the earthquake protection of buildings that has been considered in several recent experimental and theoretical studies. In particular, the friction damping bracing system involving the device proposed by Pall and Marsh (1982) has been carefully analyzed, since its simplicity of construction and high dissipative capacity encourages application in practice. At present, the existing studies offer

sufficiently detailed information about the protection level, expressed in terms of energy absorption or reduction of maximum horizontal displacement.

Friction damping devices dissipate energy by utilizing the mechanism of solid friction developed at the sliding surface, which is a relatively inexpensive and effective method for stable energy dissipation. As their hysteretic behaviors could be kept stable for cyclic loads and desirable slip loads are easily obtained by regulating normal forces acting perpendicularly to a friction surface, in addition to their simple energy dissipation mechanism and easy manufacturing, installation and maintenance (Pall and Marsh 1982). Filatrault and Cherry (1990) have proposed the design procedure of friction dampers that minimizes the sum of the displacement and dissipating energy by carrying out the parametric studies such as the structural fundamental period, frequency components of excitation load and the slip load of friction damper. Moreschi and Singh (2003) have determined the optimal slip load and the bracing stiffness by using the optimization technique such as genetic algorithm. Pujari and Bakre (2011) have studied the optimal placement of XPDs which provides more reduction in response compared with other schemes of placement of XPD considered in the study. Furthermore, the optimal placement of dampers is sensitive to the nature of excitation force, number of XPDs used and the modeling of XPD. Khante and Sanghai (2012) have studied optimal placement of friction damper using Non-Linear Time History Analysis on symmetric RCC framed building.

In this paper, a general framework for optimal placement of passive energy dissipation devices in the form of friction dampers for seismic structural application has been formulated. The study has been done for unsymmetrical RCC framed building.

2. BUILDING DESCRIPTION

The model of buildings are 6 storey and 10 storey reinforced concrete building having L shape in plan as shown in Fig.1. The building has four frames at 3m c/c in X and Y direction with 3.2m storey height and 1.2m plinth height as shown in Fig.1 and Fig.2. The beam and column are modeled as frame element while slab is modeled as thin shell element. The sizes of members are given in Table No.1. The friction dampers are placed along peripheral frames of building. The elevation of G+5 storey and G+9 storey structure with five different format of placement of dampers as shown in Fig. 2 and Fig. 3 respectively.

Table 1 Sizes of members

Storey	G+5	G+9
Sizes of Beams	0.3m X 0.45m	0.3m X 0.45m
Sizes of Columns	0.3m X 0.45m	0.3 m X 0.5m
Thickness of Slab	125mm	125mm

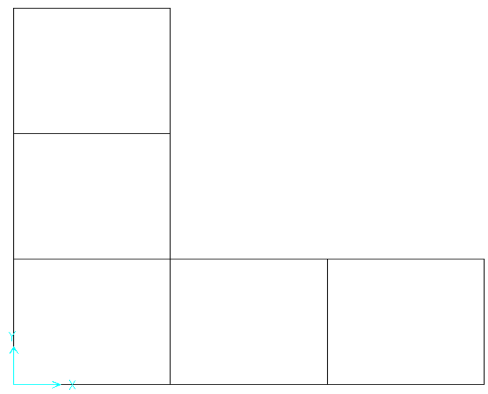
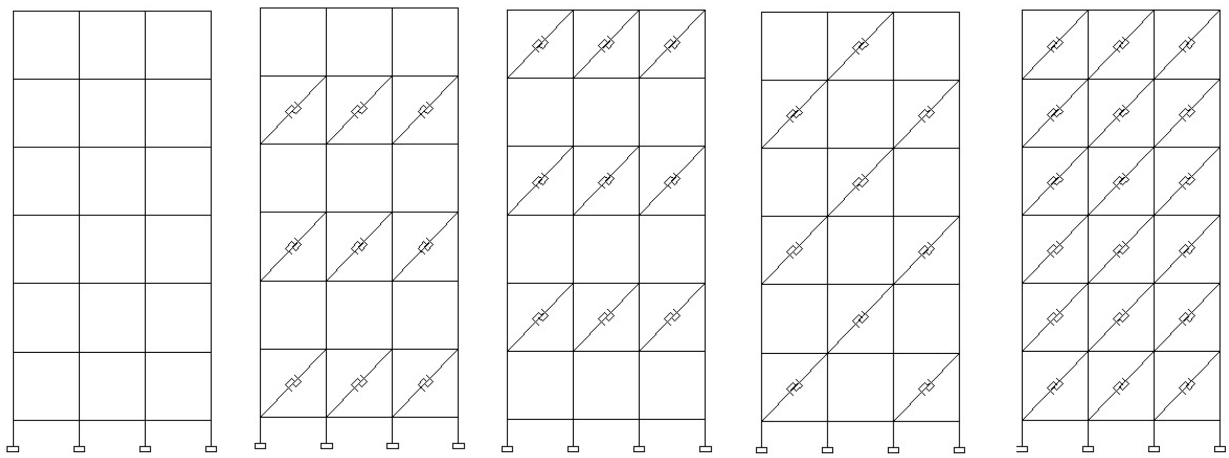
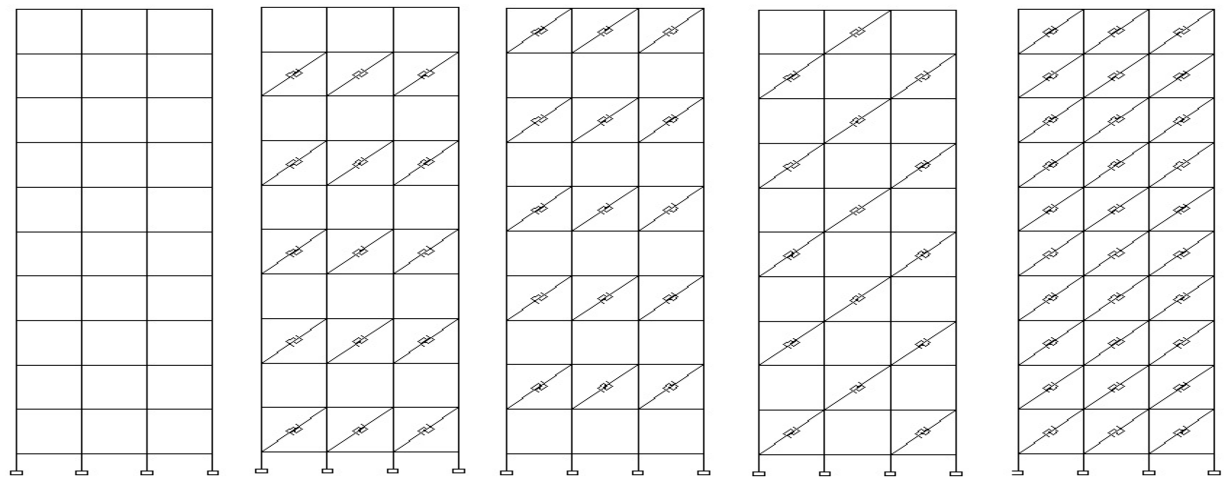


Figure 1 Plan of building



(1) (2) (3) (4) (5)

Figure 2 Elevation of formats of G+5 building model



(1) (2) (3) (4) (5)

Figure 3 Elevation of formats of G+9 building model

3. PROPERTIES OF FRICTION DAMPER

The slip load of the friction damper is the principal variable. Fig.4 shows that, if slip load is very low or very high, response is very high. This is because, if slip load is very low, friction damper will slip for small vibrations leading to minimum hysteresis energy and if slip load is very high friction damper will not slip and act as simple brace reducing hysteresis energy. The current slip load is decided by trial and error method. The appropriate selection of slip load leads to optimum response of structure. The friction dampers in single diagonal brace are modeled as damped braces having member stiffness equal to brace stiffness and nonlinear axial yielding equal to the slip load. The properties of friction damper used for modeling are given in Table No. 2.The link element named as Plastic (wen) is used to model friction damper.

Table 2 Properties of friction damper

Storey	G+5	G+9
Slip Load	300kN	500kN
Brace section	ISMB200	ISMB200
Stiffness of element	149883.99	149883.99
Yielding Load	300kN	500kN
Post yield stiffness ratio	0.0001	0.0001
Yielding Exponent	10	10

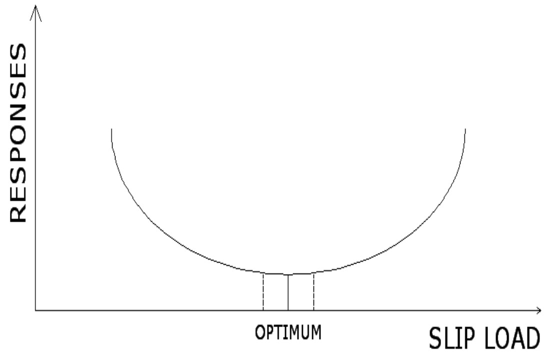


Figure 4 Responses versus Slip Load (Avtar Pall, 2004)

4. METHOD OF ANALYSIS

For the analysis of all five formats, Non-Linear Time History method has been used in SAP2000. To conduct time history analysis, the ground motion records used are El-Centro having peak ground acceleration of 0.313g and Utterkashi having peak ground acceleration of 0.252g as shown in Fig. 5 and Fig.6.

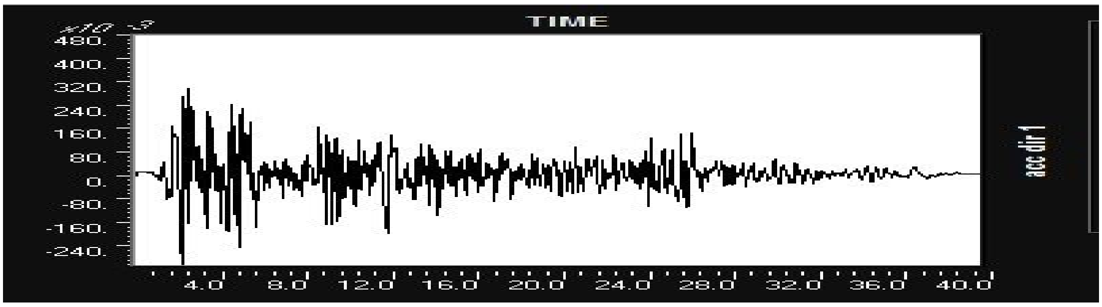


Figure 5 El Centro ground motion record

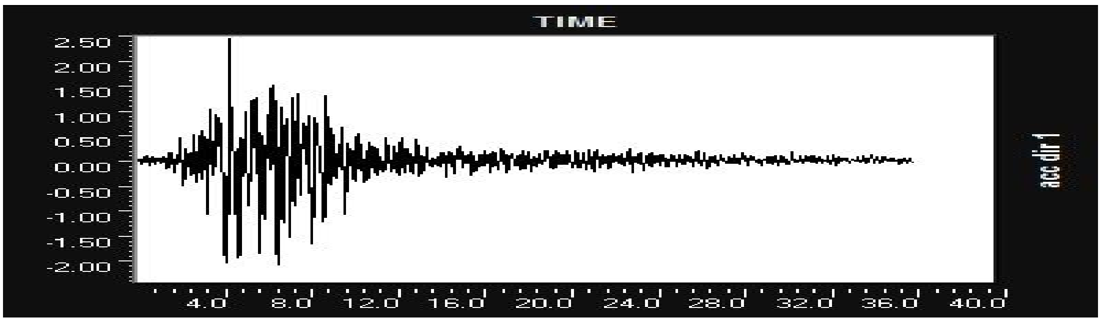


Figure 6 Utterkashi ground motion record

5. OPTIMIZATION TECHNIQUE

In this study, the friction dampers have been induced as diagonal braces in these structures with few fixed location formats. These location formats have been selected arbitrarily based on the previous study as well as with a view to keep the number of dampers used to minimum. Dampers are located between floor to floor diagonally as braces.

The unconstrained optimization problem is now formulated as:

$$\text{Minimize } f(x) = \frac{V_b}{V_{bu}} + \frac{D}{D_u} \tag{1}$$

where, $f(x)$ is the objective function to be minimized, and x is the vector of design variables. In the present case, the locations of a specified number of dampers in the structural system form the design variables. The objective function for the minimization problem is considered to be a linear combination of normalized maximum base shear V_b, and normalized maximum storey drift D. The factors V_{bu} and D_u denote the maximum base shear and maximum storey drift in the structure without any supplemental dampers (Kokil and Shrikhande, 2007

6. RESULTS AND DISCUSSION

Using SAP2000 the analysis were carried out. The comparison of results has been done to find out best optimal damper location format. The format (1) has no dampers and Format (5) has dampers at each storey, hence these two formats can't be called as optimal location formats. While in location formats (2), (3) and (4) using same number of dampers different locations have been tried. Therefore best location format will be out of Format (2), (3) and (4).

The modal time period and frequencies of mode shapes are most important factor to determine the dynamic characteristics of structure. For modal analysis, Ritz vector method has been selected for calculating time period and frequencies of mode shapes. Following table shows the modal time period and frequencies of first mode shape for different formats of friction dampers.

Table 3 Values of time period and frequencies for G+5 storey

	FOR EL CENTRO		FOR UTTERKASHI	
	TIME PERIOD	FREQUENCY	TIME PERIOD	FREQUENCY
FORMAT (1)	0.80	1.25	0.80	1.25
FORMAT (2)	0.58	1.72	0.58	1.72
FORMAT (3)	0.63	1.60	0.63	1.60
FORMAT (4)	0.52	1.91	0.52	1.91
FORMAT (5)	0.45	2.23	0.45	2.23

Table 4 Values of time period and frequencies for G+9 storey

	FOR EL CENTRO		FOR UTTERKASHI	
	TIME PERIOD	FREQUENCY	TIME PERIOD	FREQUENCY
FORMAT (1)	1.70	0.59	1.7	0.59
FORMAT (2)	1.27	0.79	1.27	0.79
FORMAT (3)	1.31	0.76	1.31	0.76
FORMAT (4)	1.19	0.84	1.19	0.84
FORMAT (5)	1.05	0.95	1.05	0.95

According to the above values, the modal time period of damped structure is less when compared with undamped structure. This is due to increase of stiffness of damped structure by addition of braces.

The envelopes of maximum values of acceleration, velocity and displacement in X direction of undamped and damped building are shown in Fig. 6, Fig. 10 and Fig. 14 for G+5 storey and Fig. 8, Fig. 12 and Fig. 16 for G+9 storey structures subjected to El Centro ground motion record while Fig.

7, Fig. 11 and Fig. 15 for G+5 storey and Fig. 9, Fig. 13 and Fig. 17 for G+9 storey structures subjected to Utterkashi ground motion record.

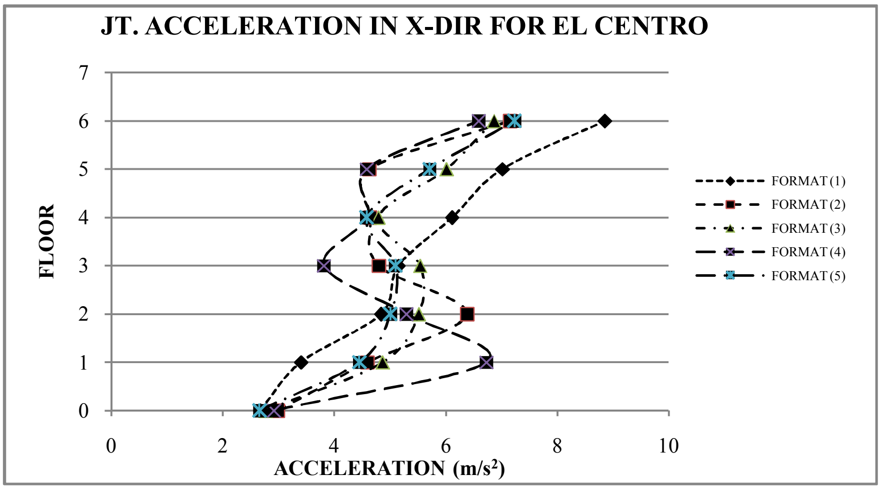


Figure 6 Jt. acceleration in X-direction for G+5 storey

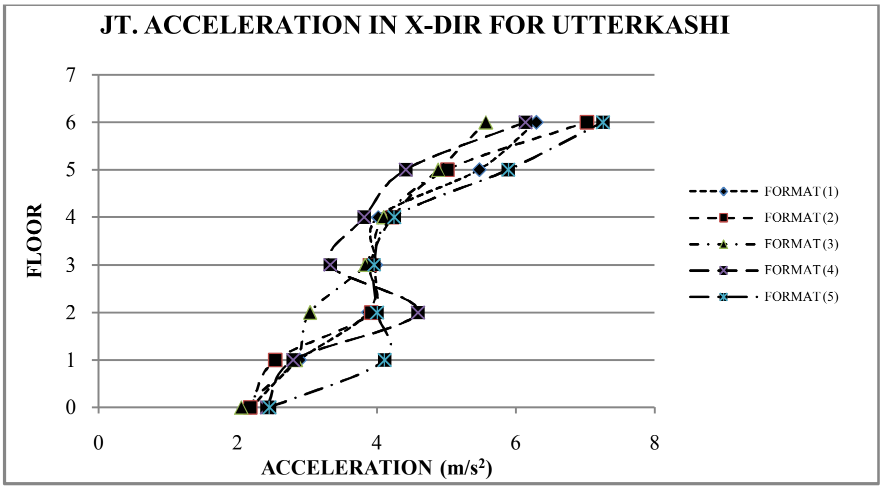


Figure 7 Jt. acceleration in X-direction for G+5 storey

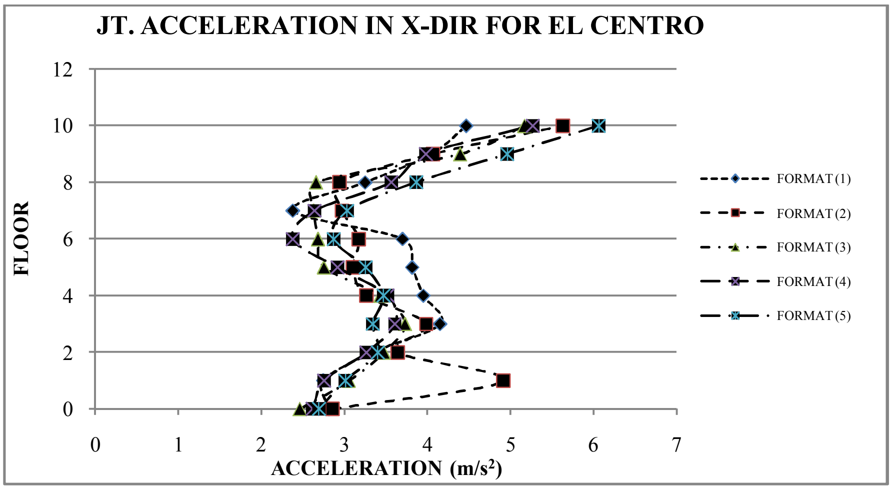


Figure 8 Jt. acceleration in X-direction for G+9 storey

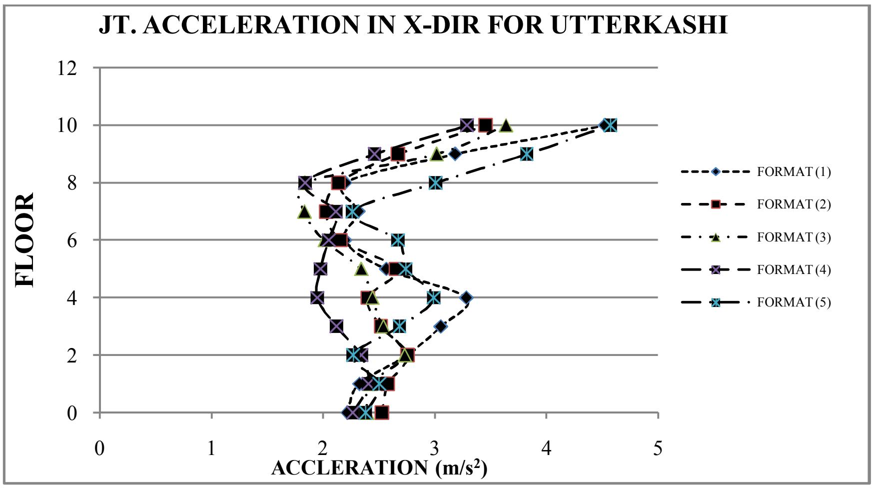


Figure 9 Jt. acceleration in X-direction for G+9 storey

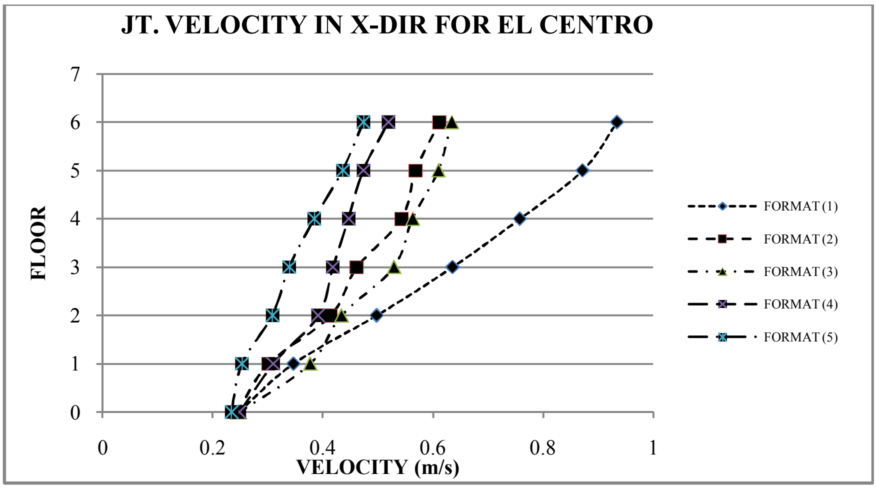


Figure 10 Jt. velocity in X-direction for G+5 storey

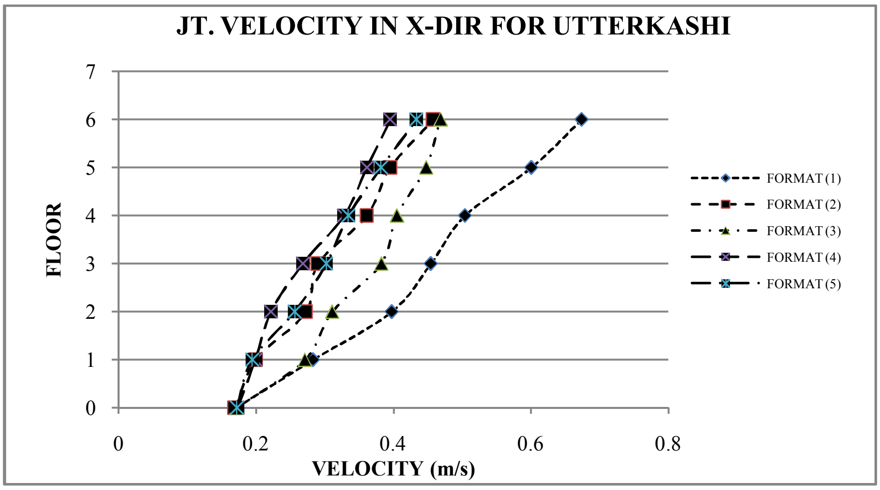


Figure 11 Jt. velocity in X-direction for G+5 storey

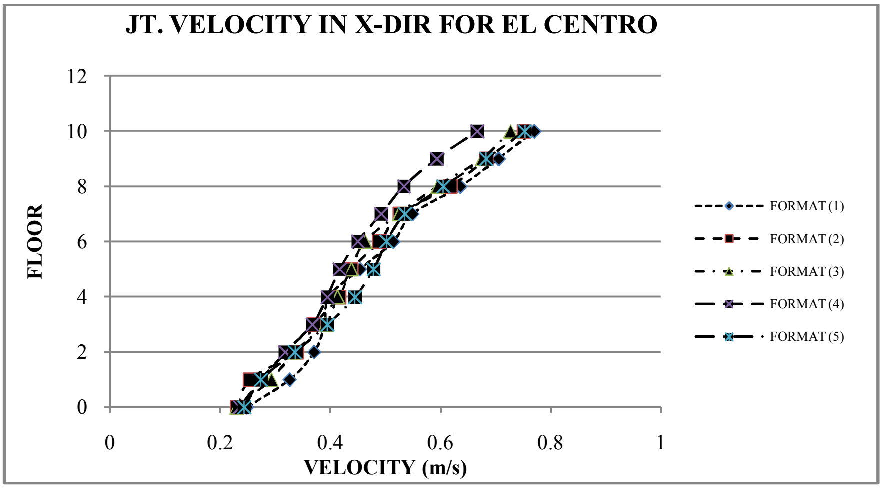


Figure 12 Jt. velocity in X-direction for G+9 storey

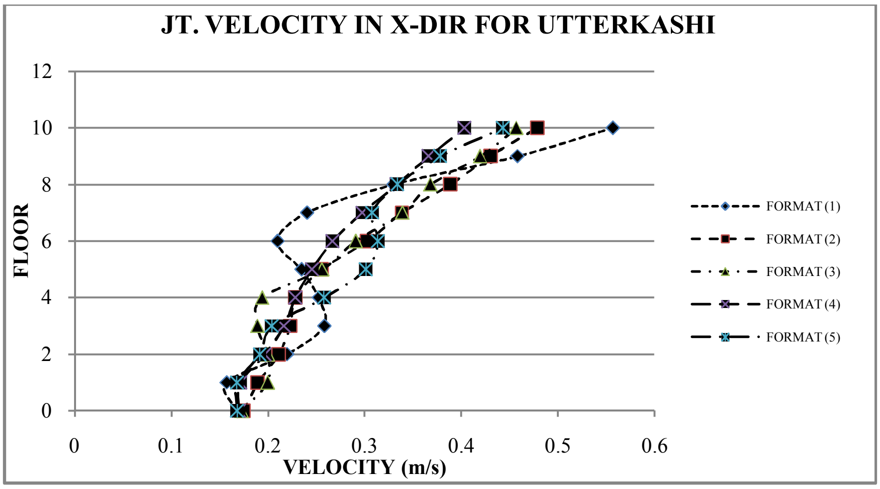


Figure 13 Jt. velocity in X-direction for G+9 storey

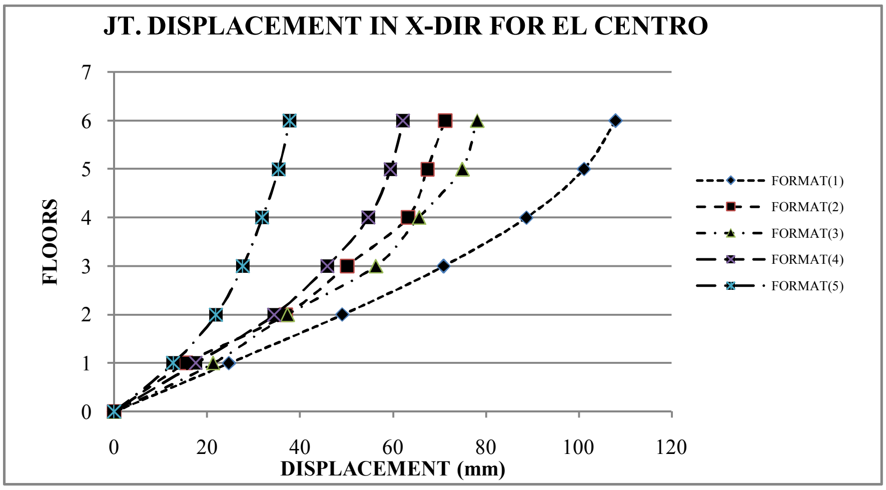


Figure 14 Jt. displacement in X-direction for G+5 storey

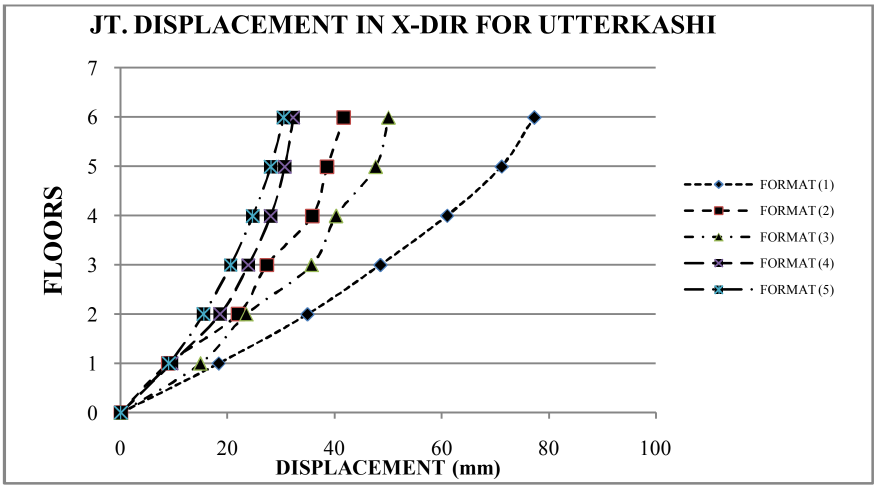


Figure 15 Jt. Displacement in X-direction for G+5 storey

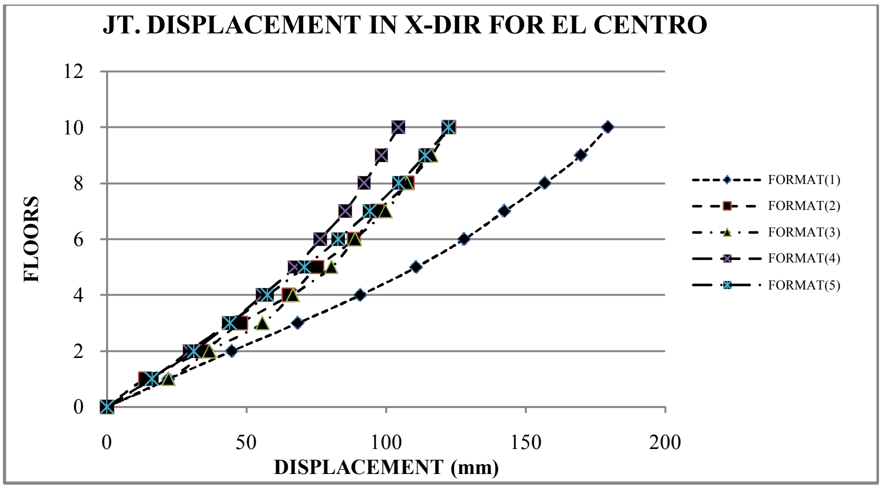


Figure 16 Jt. Displacement in X-direction for G+9 storey

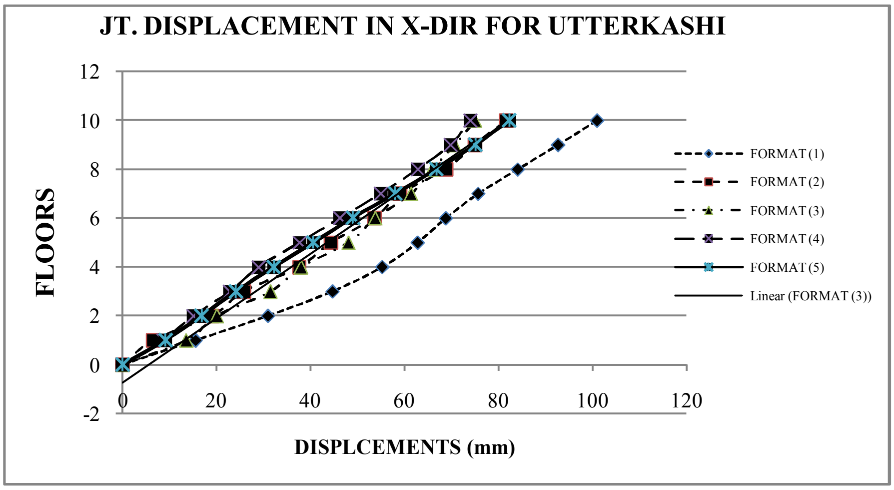


Figure 17 Jt. Displacement in X-direction for G+9 storey

From above figures, it can be seen that joint velocity and displacement in damped building in X-direction is reduced in comparison with undamped building. While joint acceleration reduces for G+5 storey and increses for G+9 storey structure. The maximum top storey reduction in joint acceleration is for Format (5) and minimum increase for Format (3), in joint velocity is for Format (4) and for Format

(4) and in joint displacement is for Format (5) and for Format (4) respectively for G+5 storey and G+9 storey structure subjected to El Centro while the maximum top storey reduction in joint acceleration is for Format (3) and for Format (4), in joint velocity is for Format (4) and for Format (3) and in joint displacement is for Format (5) and for Format (4) respectively for G+5 storey and G+9 storey structure subjected to Utterkashi. The reduction in acceleration, velocity and displacement of stories is due to increase of stiffness of structure.

The maximum base shear in X-direction of undamped and damped building is shown in Fig.18 and Fig.19.

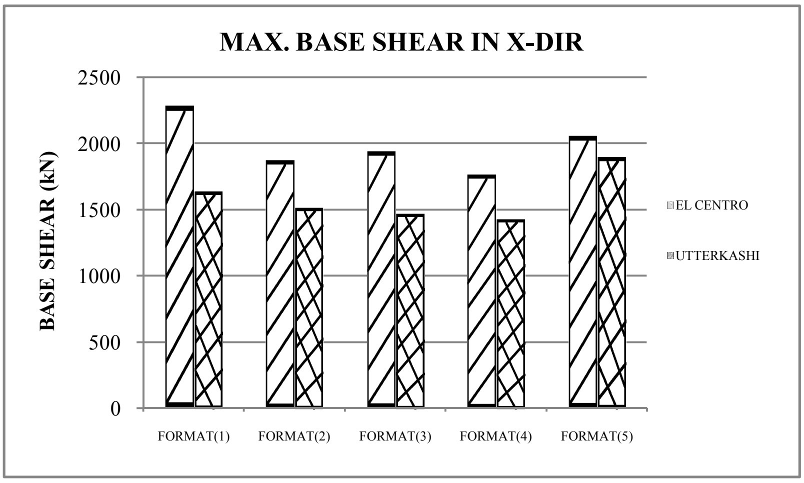


Figure 18 Maximum Base shear in X-direction for G+5 storey

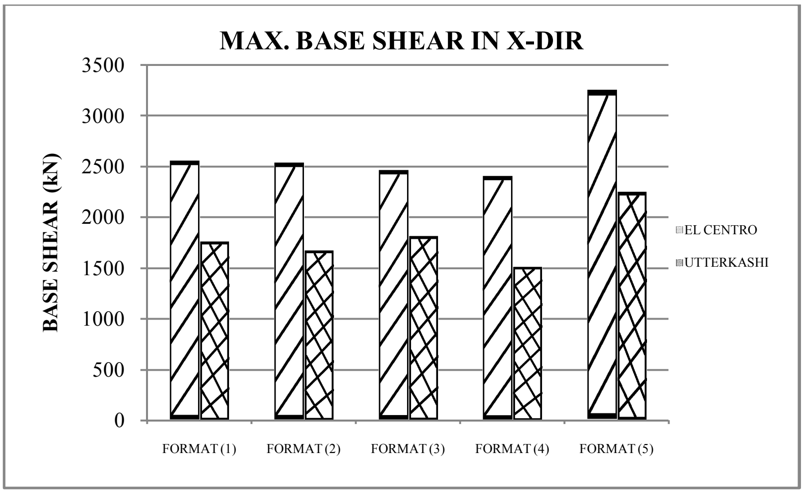


Figure 19 Maximum Base shear in X-direction for G+9 storey

Fig.18 and Fig.19 show that base shear is decreased in damped building as compared to undamped building. The maximum reduction is 22.93% for G+5 storey and 5.78% for G+9 storey structure in Format (4) subjected to El Centro ground motion record while 12.87% for G+5 storey and 14.19% for G+9 storey structure in Format (4) subjected to Utterkashi ground motion record . This reduction is due to addition of friction dampers which increases supplemental damping by 20-30%.

The maximum axial forces and maximum bending moment in members are plotted for different formats as shown in Fig. 20 and Fig. 22 for G+5 storey and Fig. 21 and Fig. 23 for G+9 storey structure.

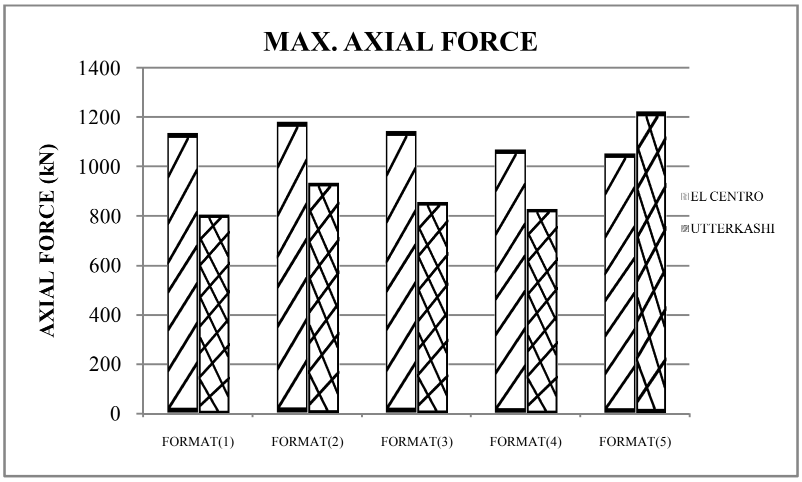


Figure 20 Maximum axial forces for G+5 storey

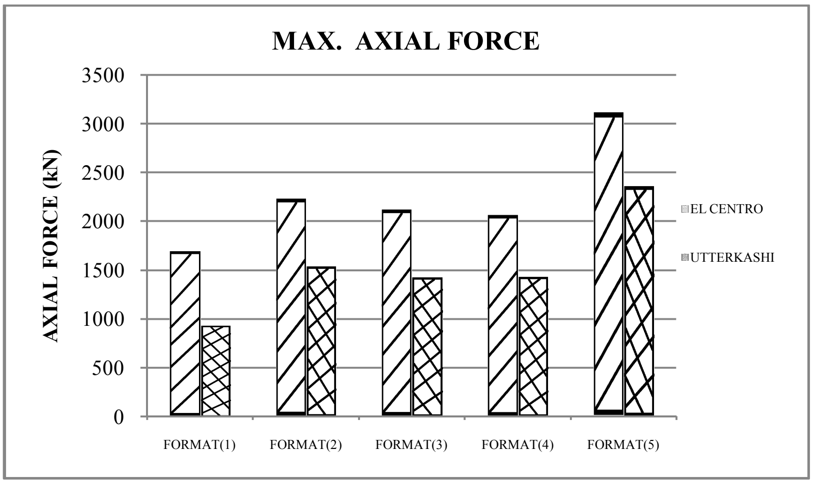


Figure 21 Maximum axial forces for G+9 storey

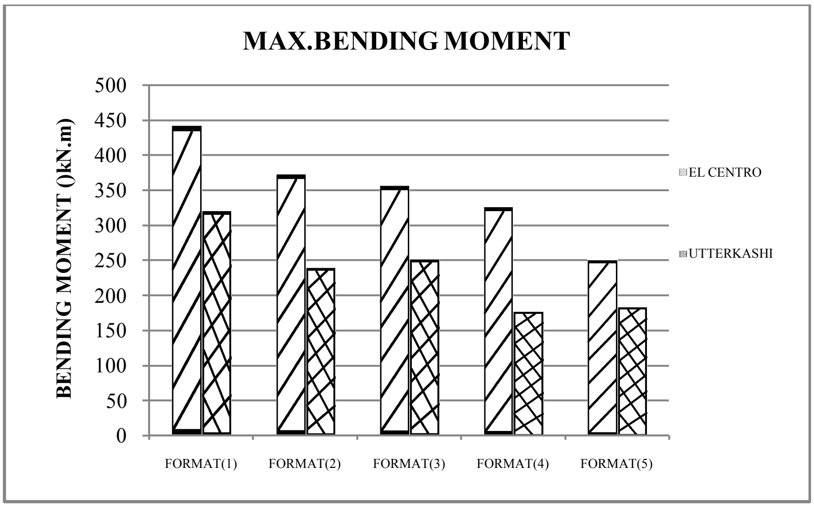


Figure 22 Maximum bending moment for G+5 storey

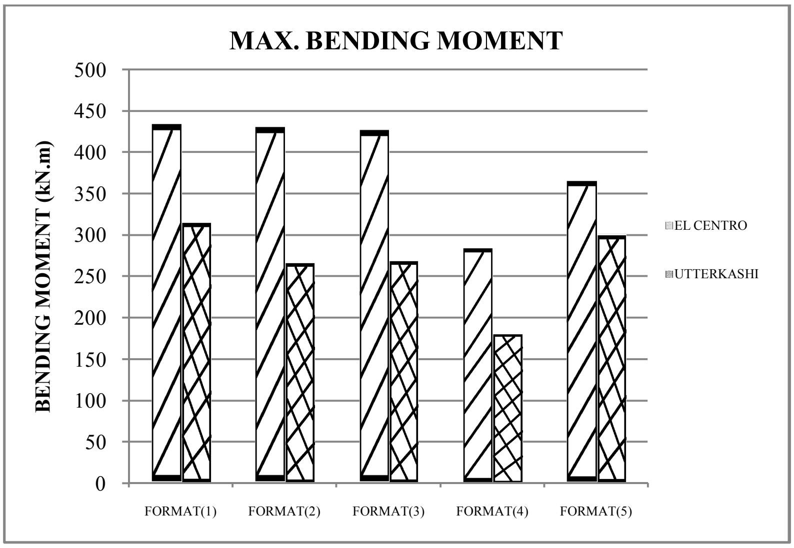


Figure 23 Maximum bending moment for G+9 storey

On comparing the maximum axial forces and maximum bending moments in members, it is observed that bending moment reduces for all models however axial force reduces for six storey building and increases for ten storey building with inclusion of damper. The earthquake forces acting on main structural member get redistributed due to addition of friction damper diagonally. This causes reduction in axial force and bending moment. It is observed that, in some cases axial force increases, because some dampers are observed to remain in non-slip mode. The reason behind it, is provision of excessive dampers and sometimes lower input acceleration. Thus they behave as bracing member. Because of this building becomes stiffer than other formats, hence axial force increases in this case.

The step by step increase in hysteresis energy for different formats of friction dampers are as shown in Fig.24 and Fig.25 for G+5 storey and Fig.26 and Fig.27 for G+9 storey structure.

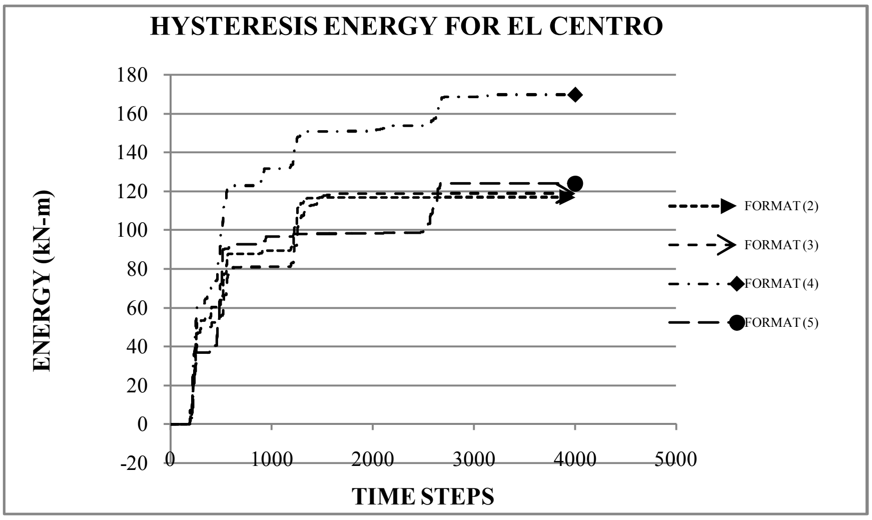


Figure 24 Hysteresis Energy for G+5 storey

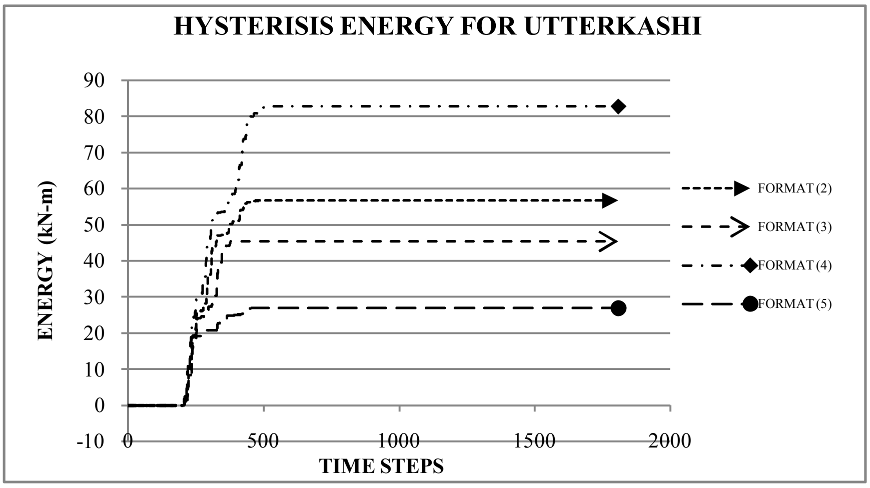


Figure 25 Hysteresis Energy for G+5 storey

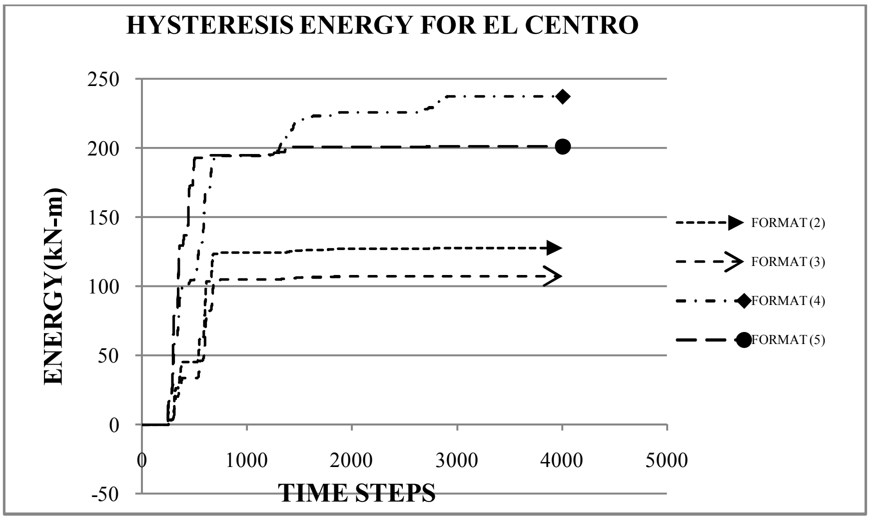


Figure 26 Hysteresis Energy for G+9 storey

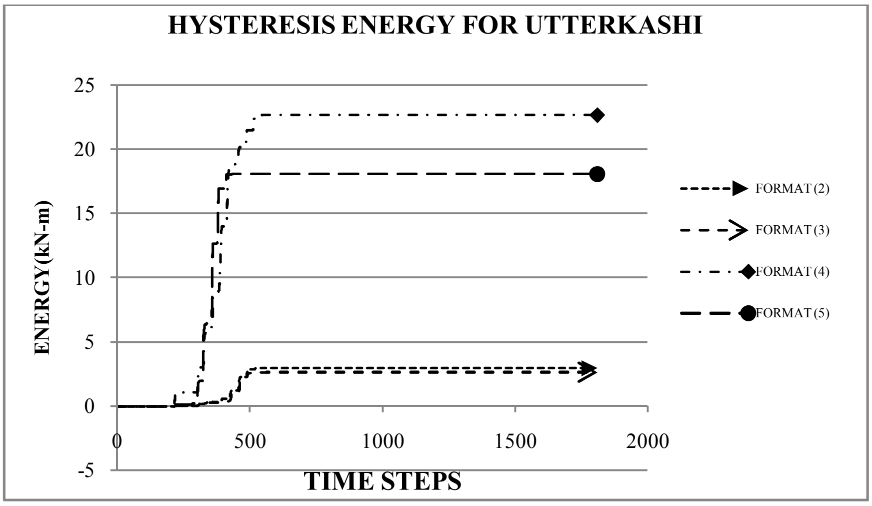


Figure 27 Hysteresis Energy for G+9 storey

From comparison of hysteresis energy, it can be seen that the maximum hysteresis energy is observed for format (4) in all cases. The more value of hysteresis energy means more amount input

energy is dissipated by friction dampers. From the figures it is clear that, by using more numbers of friction dampers does not always lead to more dissipation of input energy.

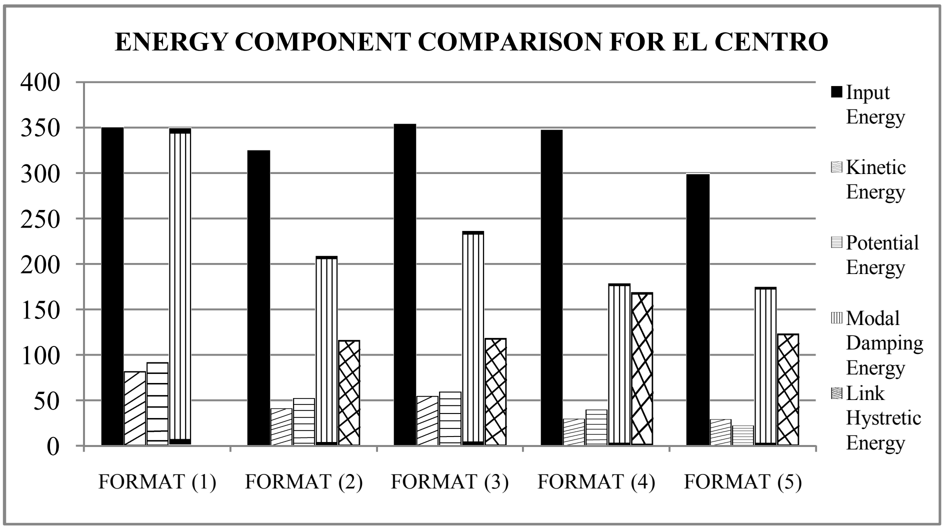


Figure 28 Different energy component comparison for G+5 storey

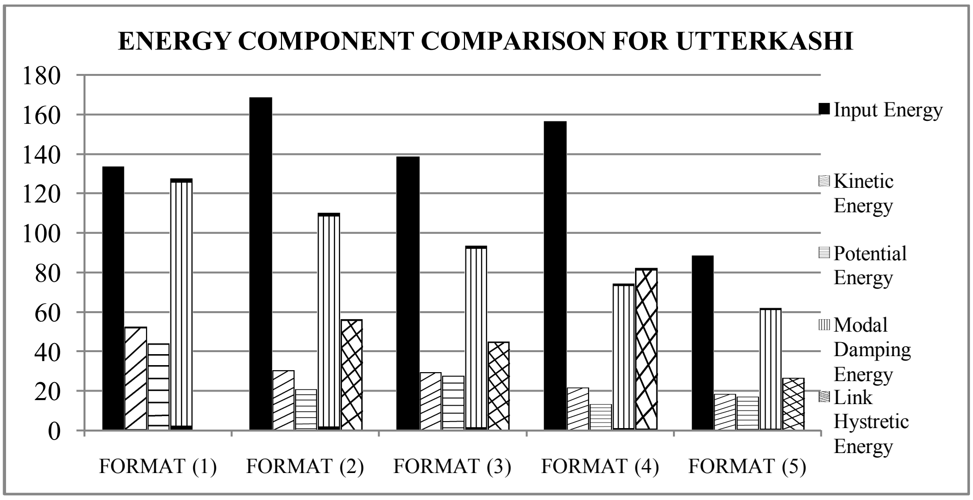


Figure 29 Different energy component comparison for G+5 storey

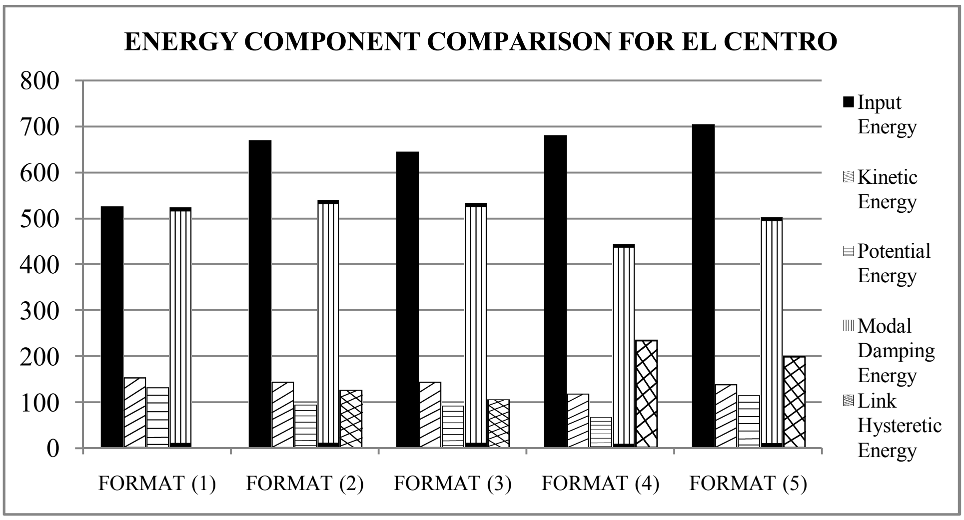


Figure 30 Different energy component comparison for G+9 storey

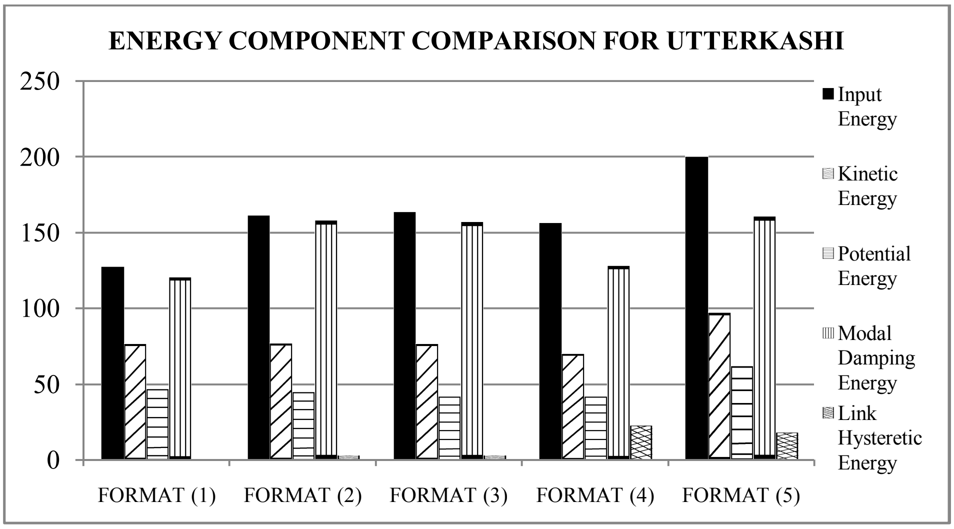


Figure 31 Different energy component comparison for G+9 storey

Fig. 28, Fig.29, Fig.30 and Fig.31 shows the different energy components for various location formats considered. The input energy depends upon work done on structure by force and acceleration and kinetic energy is function of mass and velocity while potential energy is function of elastic constant and displacement of structure. As force, mass and elastic constants of structure are same for all formats, energy components depend on acceleration, velocity and displacement of structure. In Format (1), link hysteretic energy is zero because of absence of friction damper. So, all the input energy has to be dissipated through modes so as to satisfy equation of motion. While in other formats, percentage energy dissipated through modes reduces while energy dissipated through hysteretic behaviour of friction damper increases. This reduction in percentage dissipation of input energy through modes and increase in percentage dissipation through link hysteretic behaviour depends upon location of friction damper. The percentage dissipation of input energy through hysteretic behavior is maximum for Format (4) in G+5 storey and G+9 storey building models. The value of function used for optimization is as shown in Fig.32 and Fig.33.

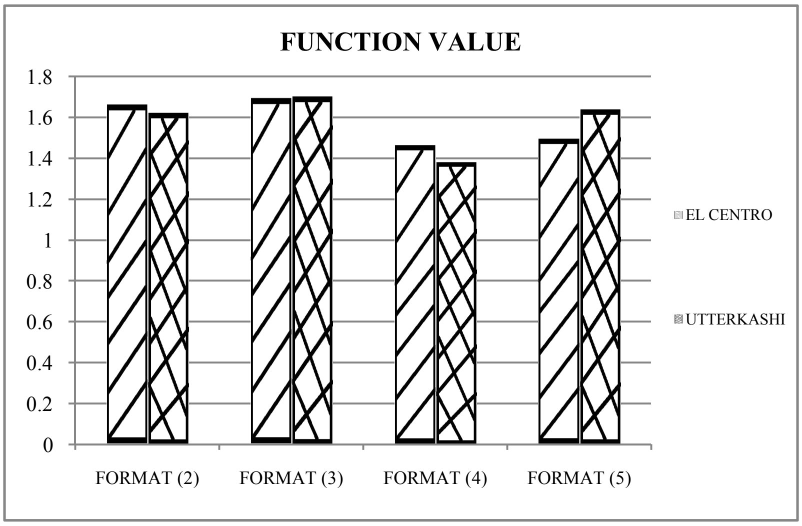


Figure 32 Objective Function Value for G+5 storey

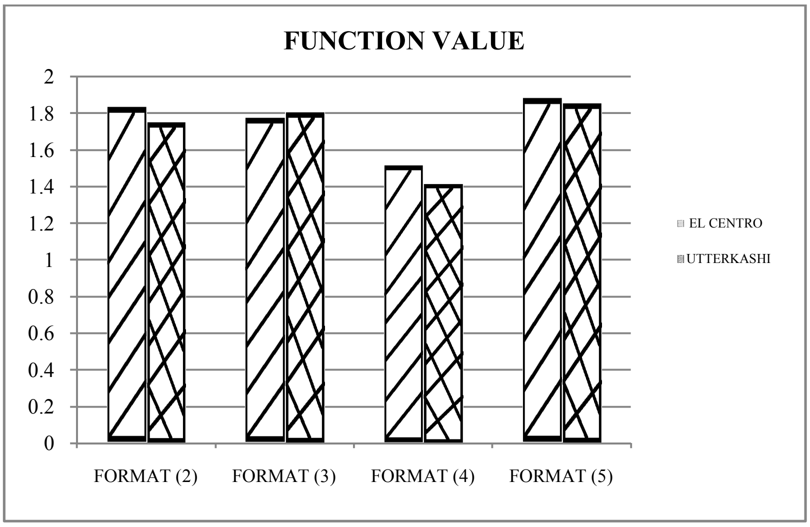


Figure 33 Objective Function Value for G+9 storey

Fig. 32 and Fig.33 shows that the value objective function is minimum for format (4) for both G+5 storey and G+9 storey structure. Also, the base shear, axial force, bending moment is minimum in format (4). Hence, it can be said that with the given no. of dampers format (4) is optimum location format.

7. CONCLUSION

The supplementary energy dissipation devices are known to be effective in reducing the earthquake induced response of structural systems. Optimal placement of these protective systems is of practical interest. The main objective of this study, therefore, has been to find the most optimal configuration of friction damper which gives maximum utilization of damper and minimal damage to unsymmetrical buildings when subjected to real earthquake ground motions. The results showed that the format (4) is the optimal format because of well distributed stiffness while in other cases alternate stories are soft and stiff. Hence it is clear that the damper placement influences significantly the structural response. Also, the study investigates that use of larger number of dampers do not always lead to the best benefit.

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